Final Report

DEN Fatigue Testing
Bid for Fixed Price Contract in response to Inquiry No: KBH-3022824

Contractor/Buyer: Bechtel Marine Propulsion Corporation, Bettis Laboratory

From: Georgia Institute of Technology

Principal Investigator: David L. McDowell, Regents' Professor
Director, Mechanical Properties Research Laboratory
4105 MRDC, GWW School of Mechanical Engineering
801 Ferst Dr.
Georgia Institute of Technology
Atlanta, GA 30332-0405
david.mcdowell@me.gatech.edu, PH: 404-894-5128, Fax: 404-894-0186

Supported by this Contract:
Richard C. Brown, Research Equipment Specialist
Georgia Institute of Technology
Mechanical Properties Research Lab
Atlanta, GA 30332-0245

Technical Contact:
Clint Geller - Clint.Geller.Contractor@unnpp.gov

Summary

In this research program that commenced in August 2010, Georgia Tech conducted a series of experiments on Double Edge Notched (DEN) specimens to explore the effects of notch root radius relative to grain size in the formation and early growth of fatigue cracks in a subject metallic material at 500°F as specified in the Inquiry. The experiments were performed in the MPRL at Georgia Tech (http://mprl.me.gatech.edu/) by Research Equipment specialist R.C. Brown.

Speciments and Test Conditions

Georgia Tech received the Double Edge Notch (DEN) specimens from Bettis based on drawing supplied by same. Length equals 5.75". Test section was approximately 1.7" long by 0.205" thick. The ends were threaded 1.5" by 14 threads per".

Deliverables: Test 10 DEN specimens at 500°F, with 4 different Load/ R ratios, an d specimens with two notch radii: 0.002" and 0.060".

All tests were performed using a 50,000 lb MTS 810 tests system. An MTS Test Star 2 controller was employed for test control and data acquisition for all tests.

Test conditions were specified in the Table below from Bettis. Test condition **D-1** was to be 0.002" notch root radius, fully reversed at 10 Hz, with 5700 lb load amplitude. In the initial calibration test it was discovered that that load was too high and a maximum load of 5200 lb was selected for all tests except the D-4 condition tests.

Test condition **D-2** was to be 0.002" radius, at 5 Hz, R = 0.2, 5200 lb peak load.

Test condition **D-3** was to be 0.002" radius, at 1o Hz, R = 0.5, 5200 lb peak load.

Test condition **D-4** was to be 0.060" radius, at 10 Hz, R = 0.2, 5700 lb peak load.

Table 1. DEN Specimen Matrix for Mean Stress FCI Test

Case	R Value	Notch Radius (mils)	# Replicates	Load[a] (Lbs)	Frequency (Hz)
D – 1	- 1.0	2	2	5770	1
D – 2	+0.2	2	2	5770	5
D – 3	+0.5	2	2	5770	10
D – 4	+0.2	60	2	5770	10
EPD-C	Calibration specimens	2	2	TBD[b]	TBD[b]

a: This load gives an Smax of 25 Ksi. This is to be increased linearly to the value specified in the table over the first 100 cycles, to prevent excessive notch root deformation
b: Vendor shall determine the loads and frequencies for the calibration tests, and report them

Included in this shipment are the following specimens for use in purchase order 3022824:

Specimen Type No.	Total Qty.	Drawing No.	Drawing Rev.	Specimen Description	Specimen Identification
1	*3*	*9044C24*	-	DEN R=.060	SCGD-01 through SCGD-03
2	*8*	*9044C86*		DEN R=.002	SCGD-04 through SCGD-11

Specimens were machined from 304SS plate, Heat 39E5.

Two specimens from specimen type 1 (root radius of 0.060 in) and six specimens from specimen type 2 (root radius of 0.002 in) are for performing testing required in subcontract.

The remaining three specimens are for Georgia Tech's use in performing EPD calibration tests or checking test setup, two with R=0.002 and one with R=0.060.

All eleven specimens shall be returned to Bechtel Bettis after the test contract is complete.

The Electrical Potential Drop System (EPD) was constructed using a Sorensen 10-25 DC Power supply, An Omega Omni Amp set to a gain on 1000X, with spot welded high temp leads located at the centerline for input and across the notch for readout. Current was controlled at test start to give an output of 0.2 volts by adjusting the supply current. At no time did the input current exceed 3 amps. A secondary computer with a 12 bit National Instruments multi function card was used to acquire the amplified EPD signals and compute the mean over 1000 samples. The National Instruments card outputted this value to

be stored with segment counts in the MTS system. Note: 2 segments equal 1 cycle. All segment counts were converted to cycles in the Excel spreadsheet.

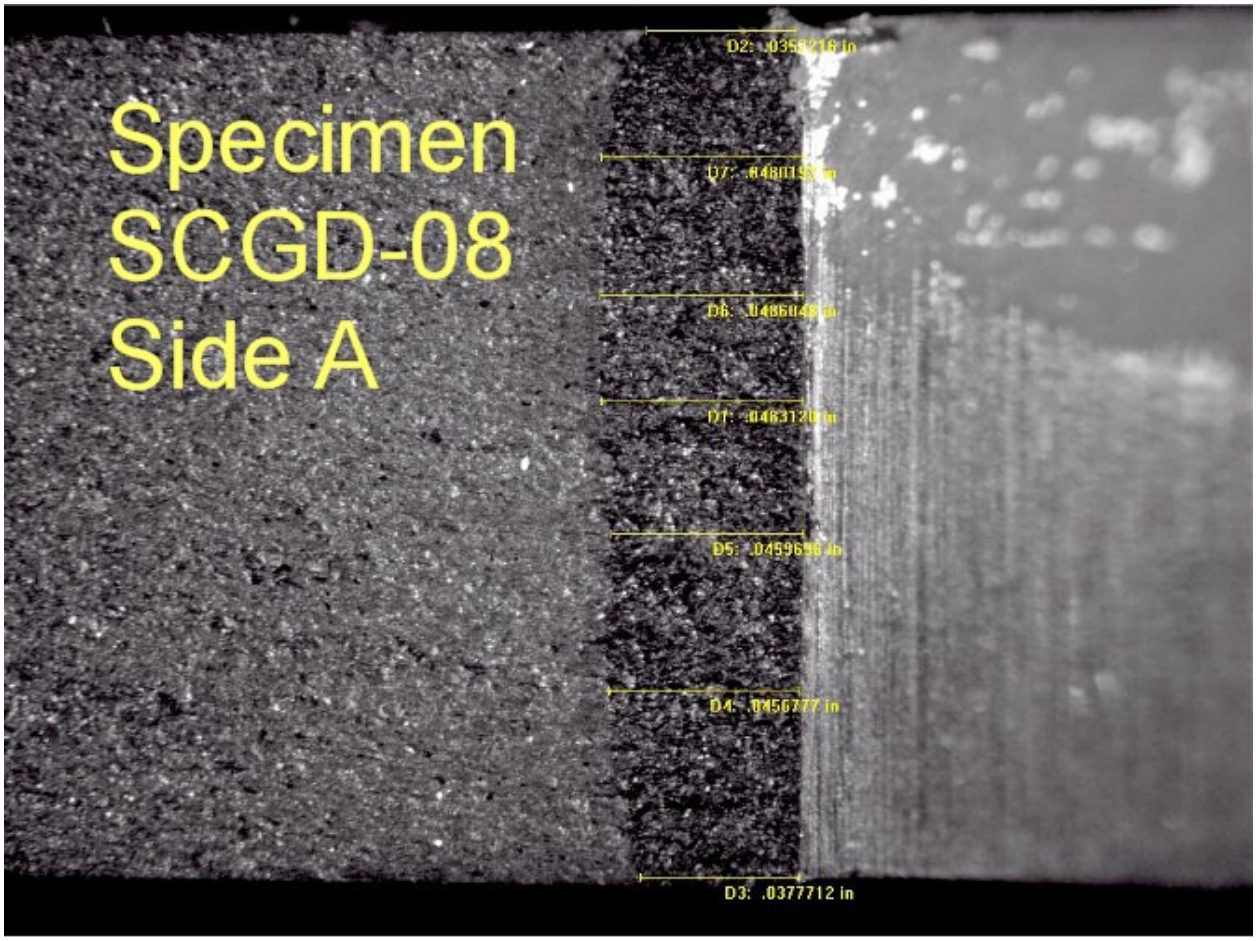
All specimen notch root regions were visually observed during testing using two Questar QM-100 long focal length microscopes fixed at 300X magnification to detect fatigue cracks.

THIS REPORT AND ALL DATA FILES WILL BE SENT TO BETTIS ON CD-ROM AS SPECIFIED IN THE INQUIRY, AND SPECIMENS WILL BE RETURNED AS SPECIFIED THEREIN.

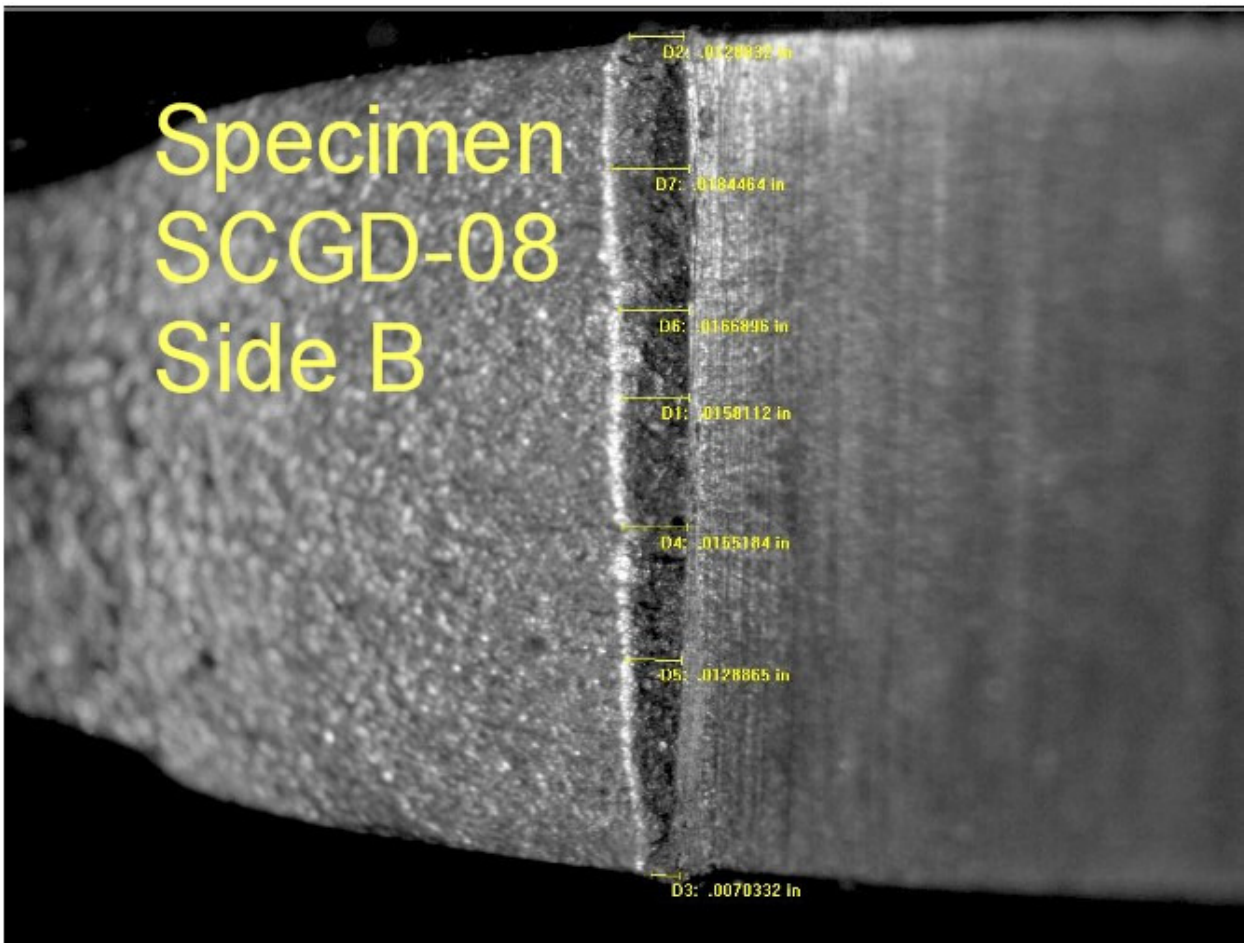
Specimen Photos and Results Summary

Test Condition D-1

Specimen SCG- 08 Test Condition D-1 R = -1 Max. Load 5200 lb notch radius = 0.002”
Total Cycles = 1522



Side1+Side2/2 = 0.037” Avg. Crack Length = 0.046”
.010” on side = 632 Cycles



Side1+Side2/2 = 0.010” Avg. Crack Length = 0.015”

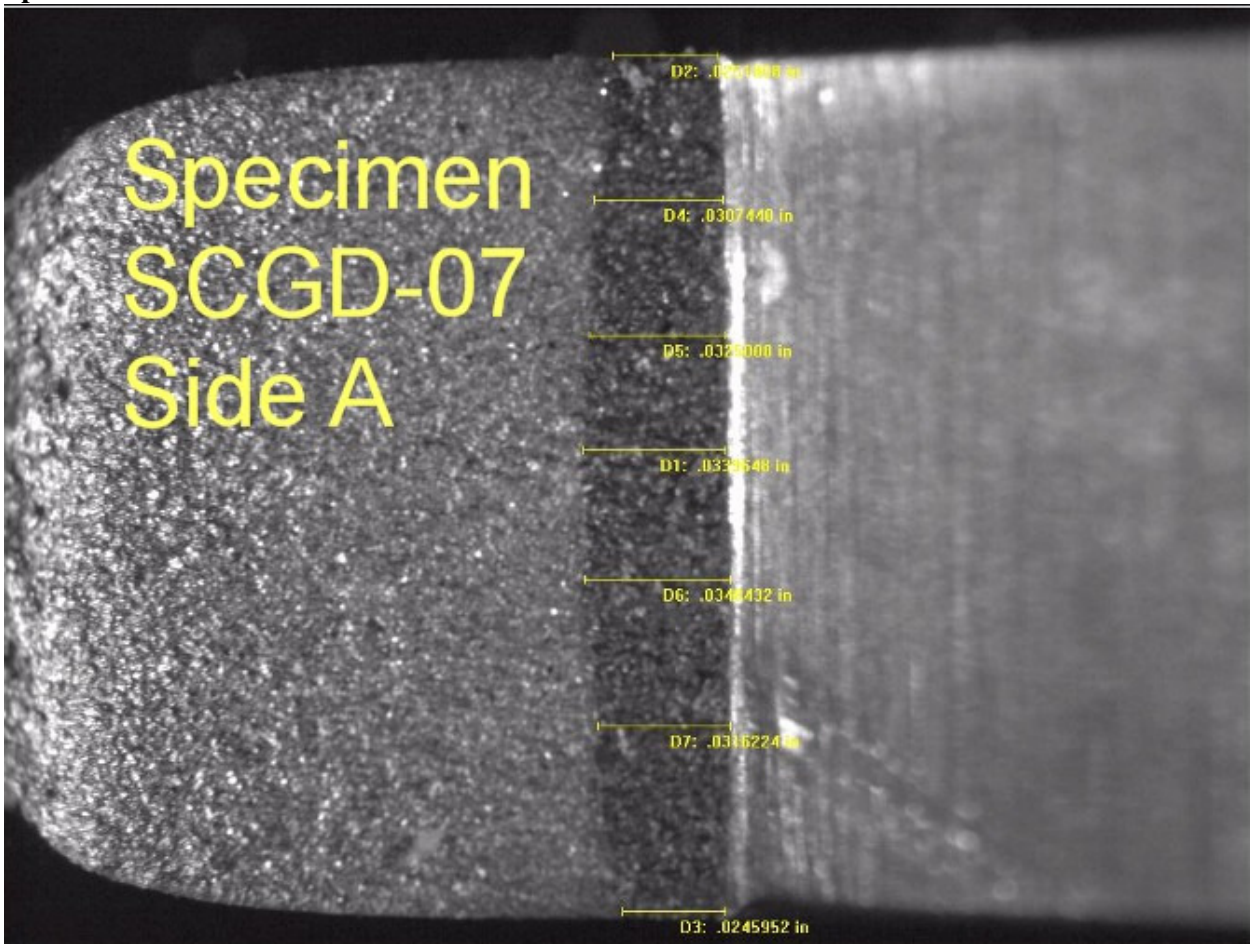
Visual Measurements (Inside face of notch)

Cycles	Side				EPD	
	A1	A2	B1	B2	A (mv)	B (mv)
0	0.00	0.00	0.00	0.00	147	152
632	0.00	0.00	.010	.010	151	162
1524	0.00	0.00	.037	.060	151	161

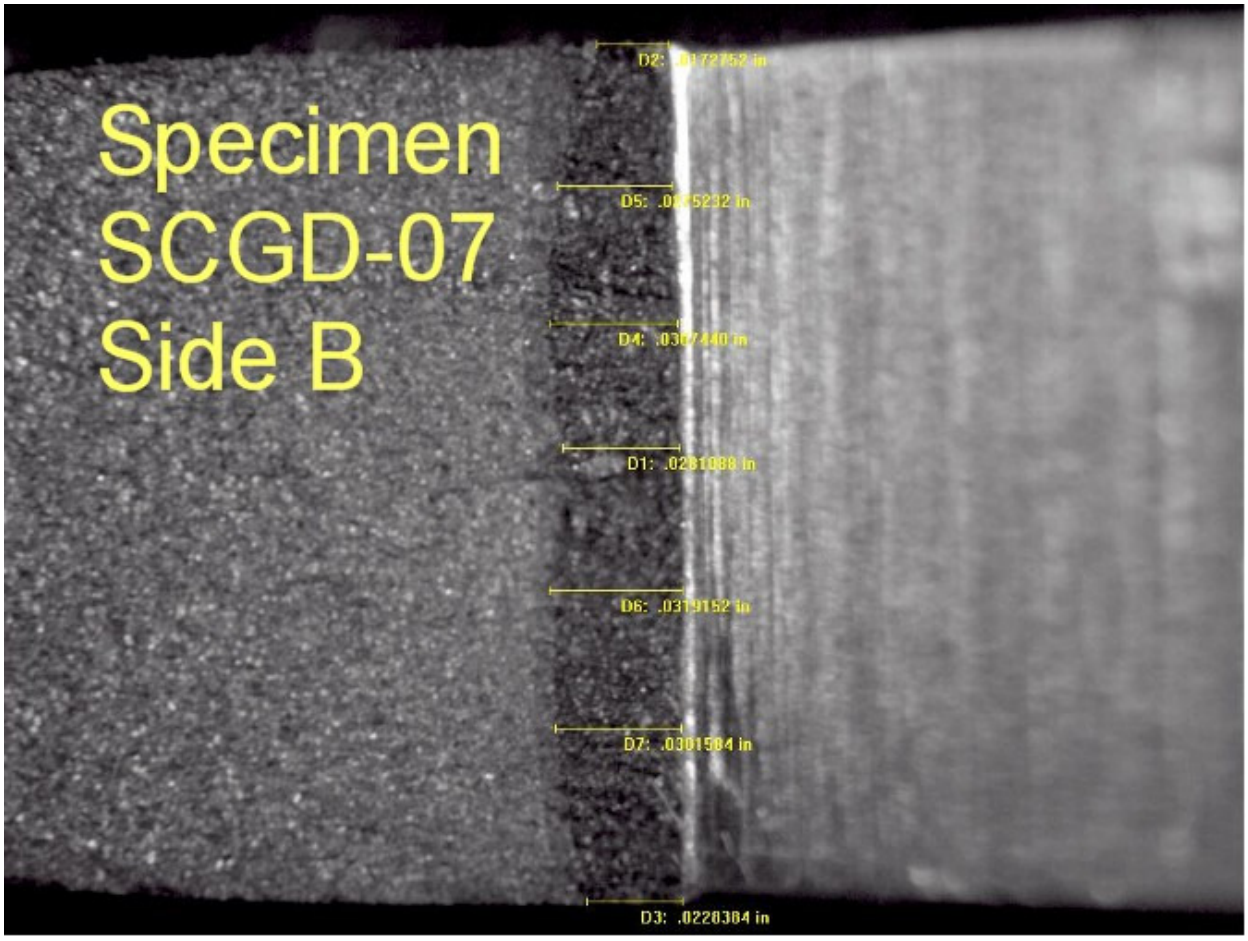
Crack length in inches.

Specimen was re-run until crack = .025” on the side. See XLS spreadsheet for **SCGD-08.**

Specimen SCGD – 07 Test Condition D-1 R = -1 notch radius = 0.002" 1Hz Max Load = 5200 lb.



Side1+Side2/2 = 0.0225" Avg. Crack Length = 0.031"



Side1+Side2/2 = 0.02" Avg. Crack Length = 0.0285"

Visual Measurements (inside face of notch)

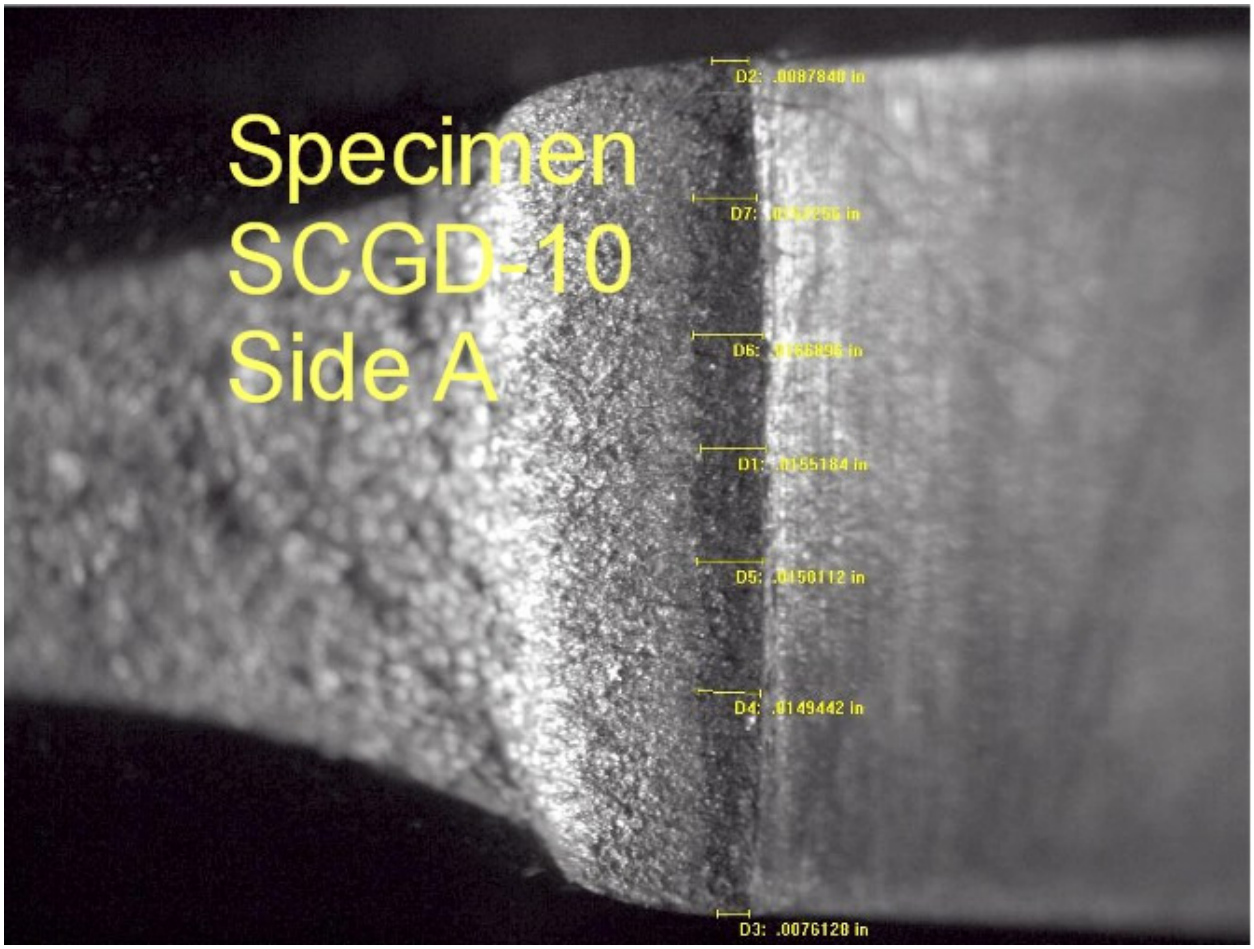
Cycles	Side		EPD	
	A	B	A	B
0	0.00	0.00	210	200
500	0.00	0.00	205	195
1000	0.00	0.00	210	190
1587	.005	.150	216	210

Note: crack length in inches.

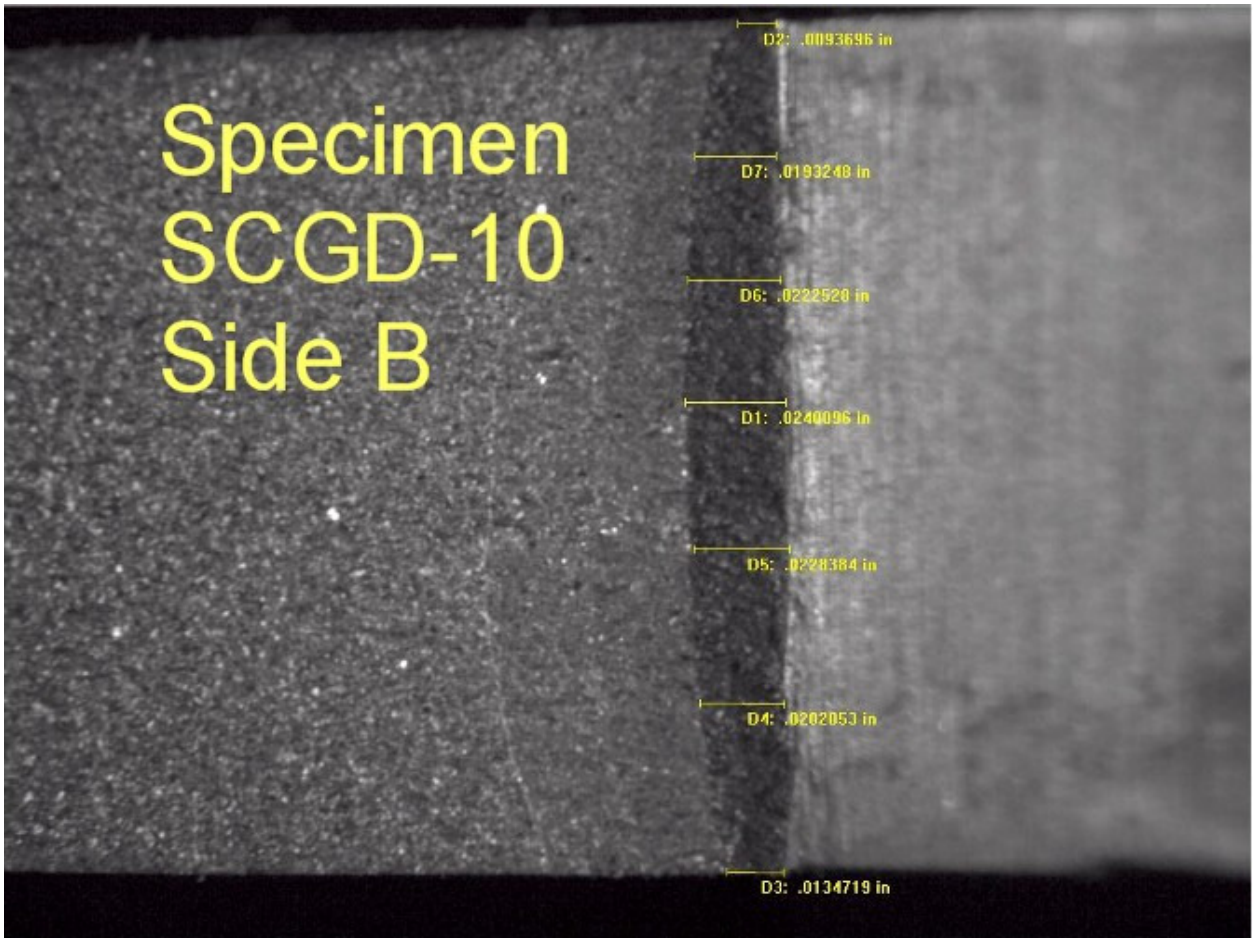
Specimen was re-run until crack length = 0.025" on side of specimen. See Excel spread sheet for **SCGD-07** for EPD data.

Test Condition D-2

Test Condition **D-2** Radius 0.002”, R ratio = 0.2 Max load 5200 lb, 5 Hz.
Specimen SCGD – 10 Test Condition D2 R = 0.2 notch radius = 0.002” Max Load = 5200 lb.



Side1+Side2 = 0.0085” Avg. Crack Length = 0.014”



Side1+Side2/2 = 0.0115 Avg. Crack Growth = 0.020”

Visual Data

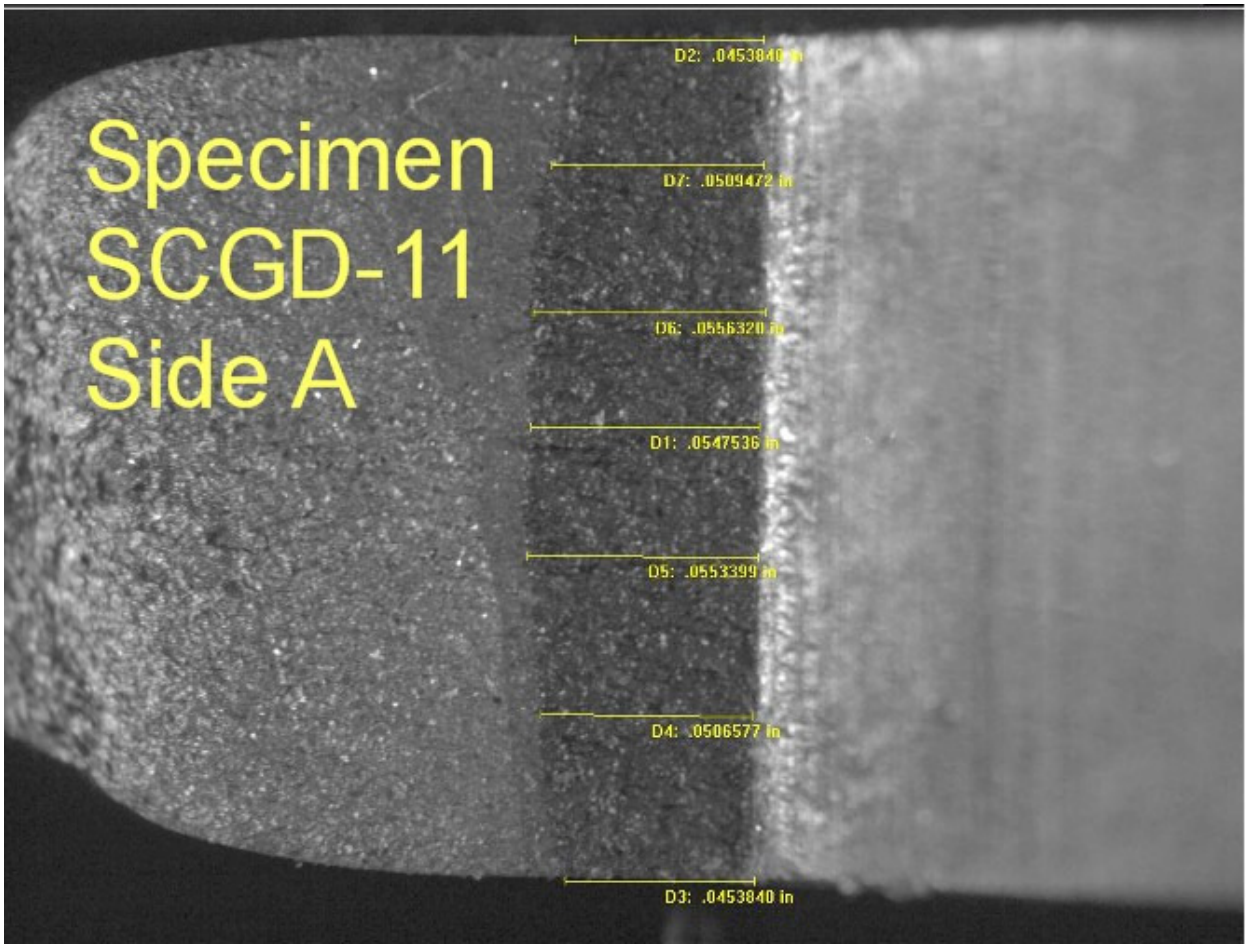
Cycles	Side A1	A2	B1	B2
9785	0.00	0.00	0.00	0.00
14783	0.00	0.00	0.00	0.00
16068	0.00	0.00	0.005	0.007
16960	0.00	0.00	0.008	0.010
19600	0.00	0.00	0.011	0.016
20412	0.00	0.00	0.016	0.020
21543	0.00	0.00	0.016	0.025

Note: crack length in inches.

See Excel spread sheet for **SCGD-10** for EPD data.

Test Condition D-2

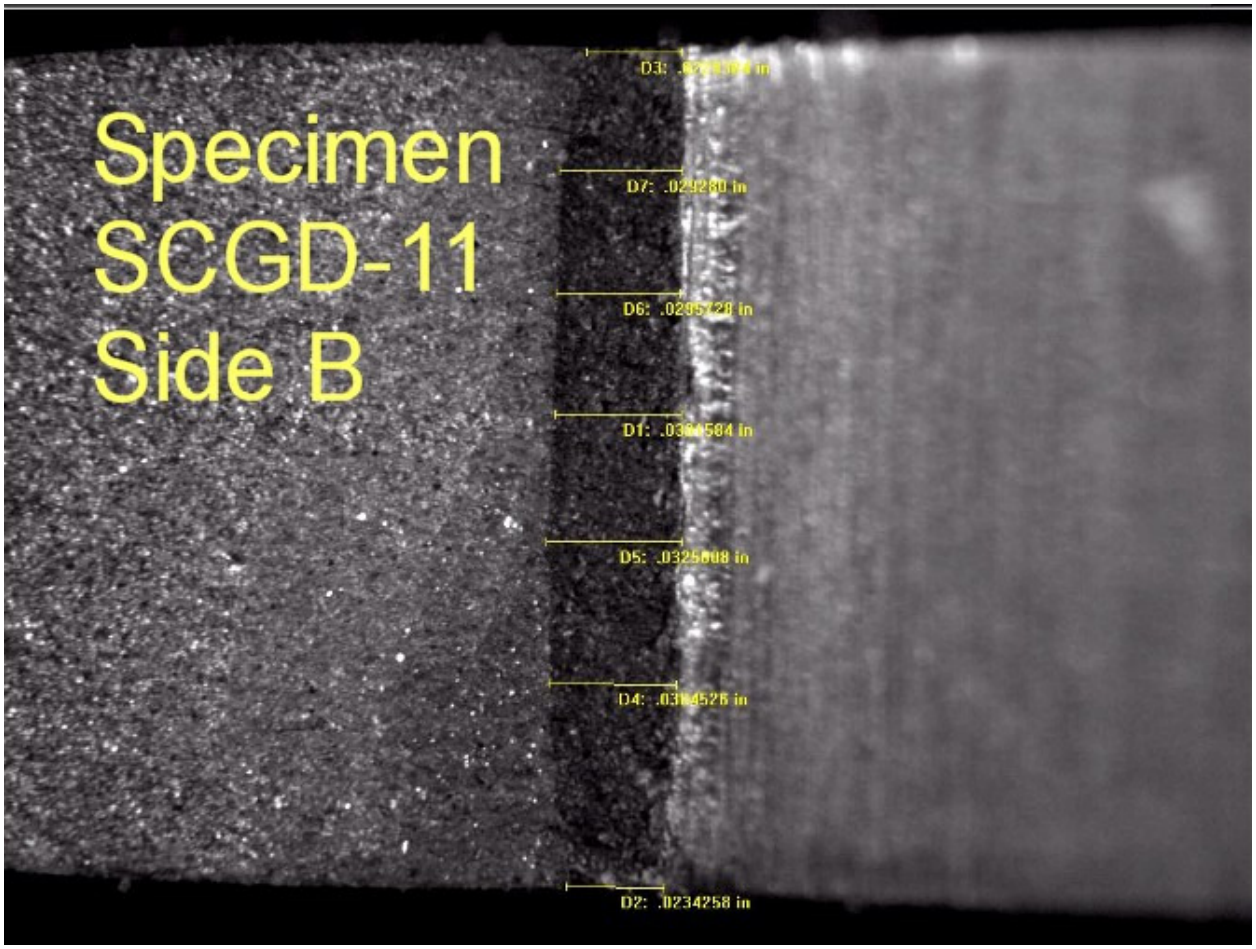
Specimen – SCGD 11 Test Condition D-2 R = 0.2 notch radius = 0.002” Max Load = 5200 lb.



Side1+Side2/2 = 0.045” Avg. Crack Length = 0.052”

No Visual data. EPD stopped test at 9996 cycles.

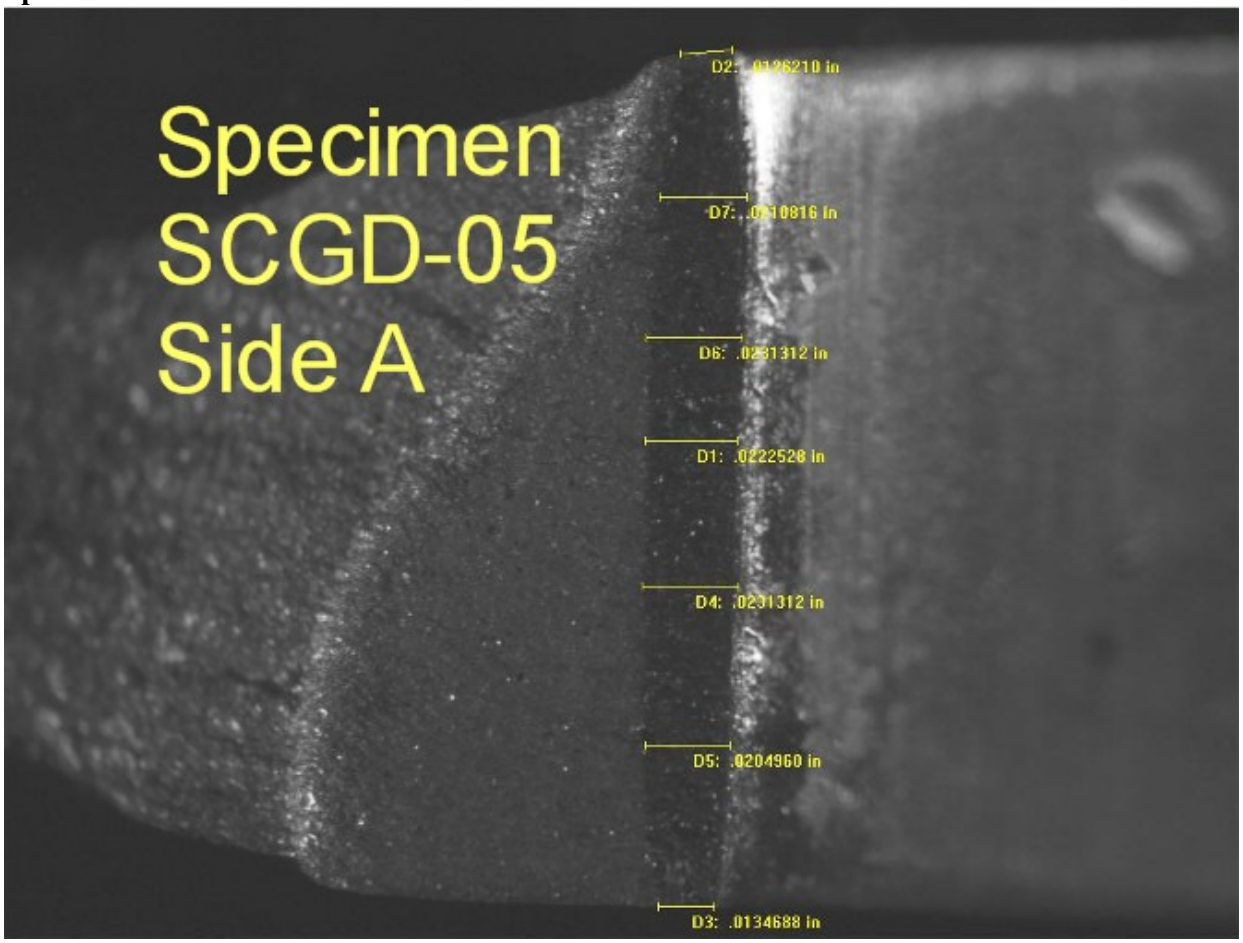
See Excel spread sheet for **SCGD-11** for EPD data.



Side1+Side2/2 = 0.022” Avg. Crack Length = 0.030”

Test Condition D-3

Specimen SCGD-05 Test Condition D-3 R = 0.5 notch radius = 0.002" Max. load 5200 lb.



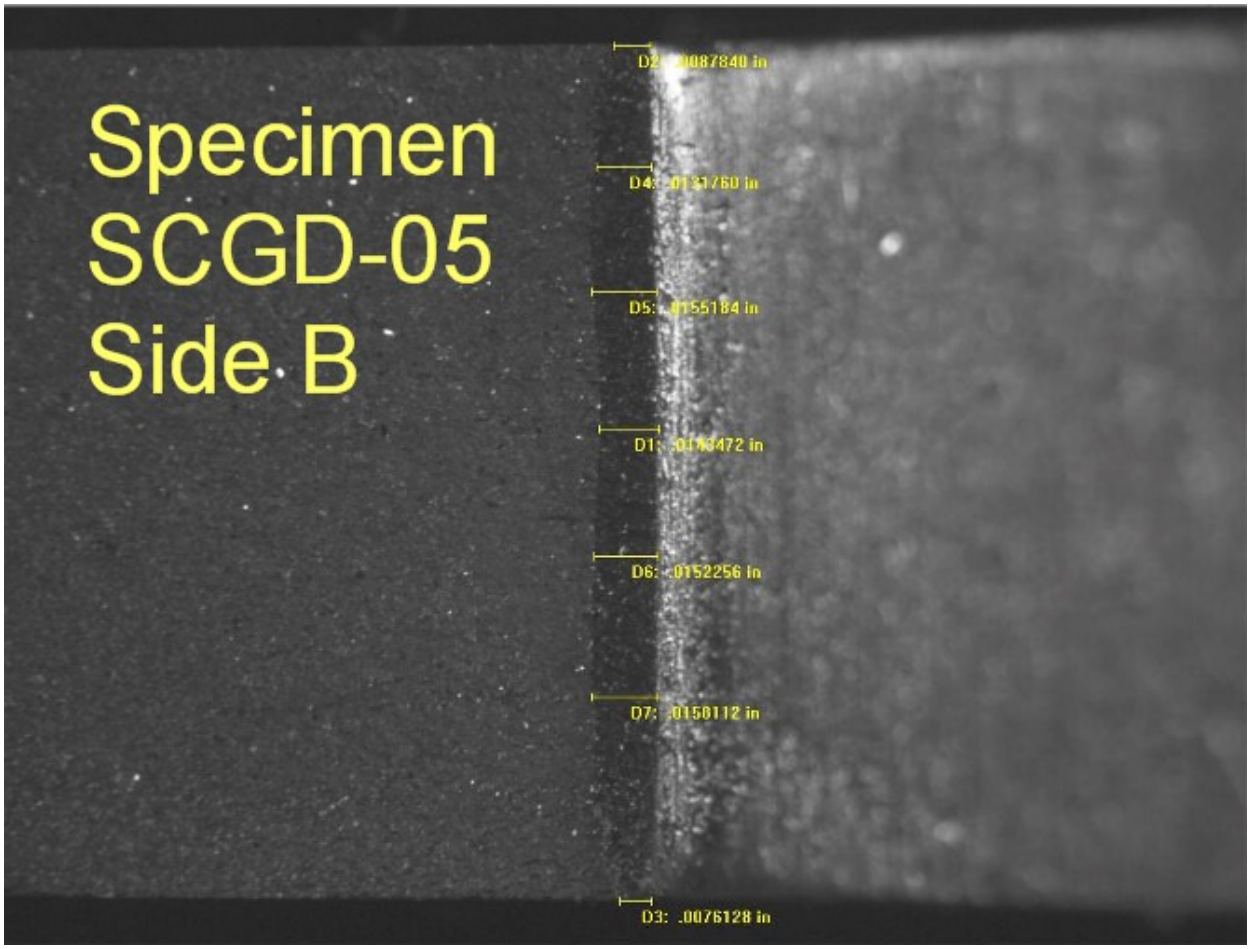
Side1+side2/2 = 0.0135" Avg. Crack length for 7 readings = 0.021"

Visual Readings Side

Cycles	A1	A2	B1	B2
10K	0.00	0.00	0.00	0.00
30K	0.00	0.00	0.00	0.00
50K	0.00	0.00	0.00	0.005
70004	0.005	0.010	0.00	0.005
72496	0.005	0.0175	0.00	0.005
80004	0.010	0.0175	0.00	0.007
90004	0.020	0.029	0.00	0.010

Note: crack lengths in inches

See Excel spread sheet for **SCGD-05** for EPD data.



Side1+side2/2 = 0.0075” Avg. Crack Length = 0.010”

Specimens SCGD 04 and 06 were tested at these test conditions. Tests were stopped when a crack of 0.025” inside the notch root was visually observed. These two specimens were returned to Bettis for serial sectioning.

Specimen SCGD-06 Test Condition D3 R = 0.5 10 Hz Total Cycles to stop test = 100,000.
Crack inside of notch only Side A = .025" Side B = 0.0"

Specimen Returned to Bettis No Photos
Visual Data

Cycles	Side A	Side B
7600	0.00	0.00
15.5K	0.00	0.00
20K	0.00	0.00
50K	0.00	0.00
70K	0.00	0.00
90K	0.005(some uncertainty)	0.00
100K	0.025	0.00

Note: crack lengths in inches

Crack in notch face. Specimen stopped, sent to Bettis for serial sectioning.
Crack only visible under load.

Specimen SCGD -04 Test Condition D-3 R = 0.5 notch radius = 0.002" Max Load 5200 lb.
Specimen returned to Bettis.

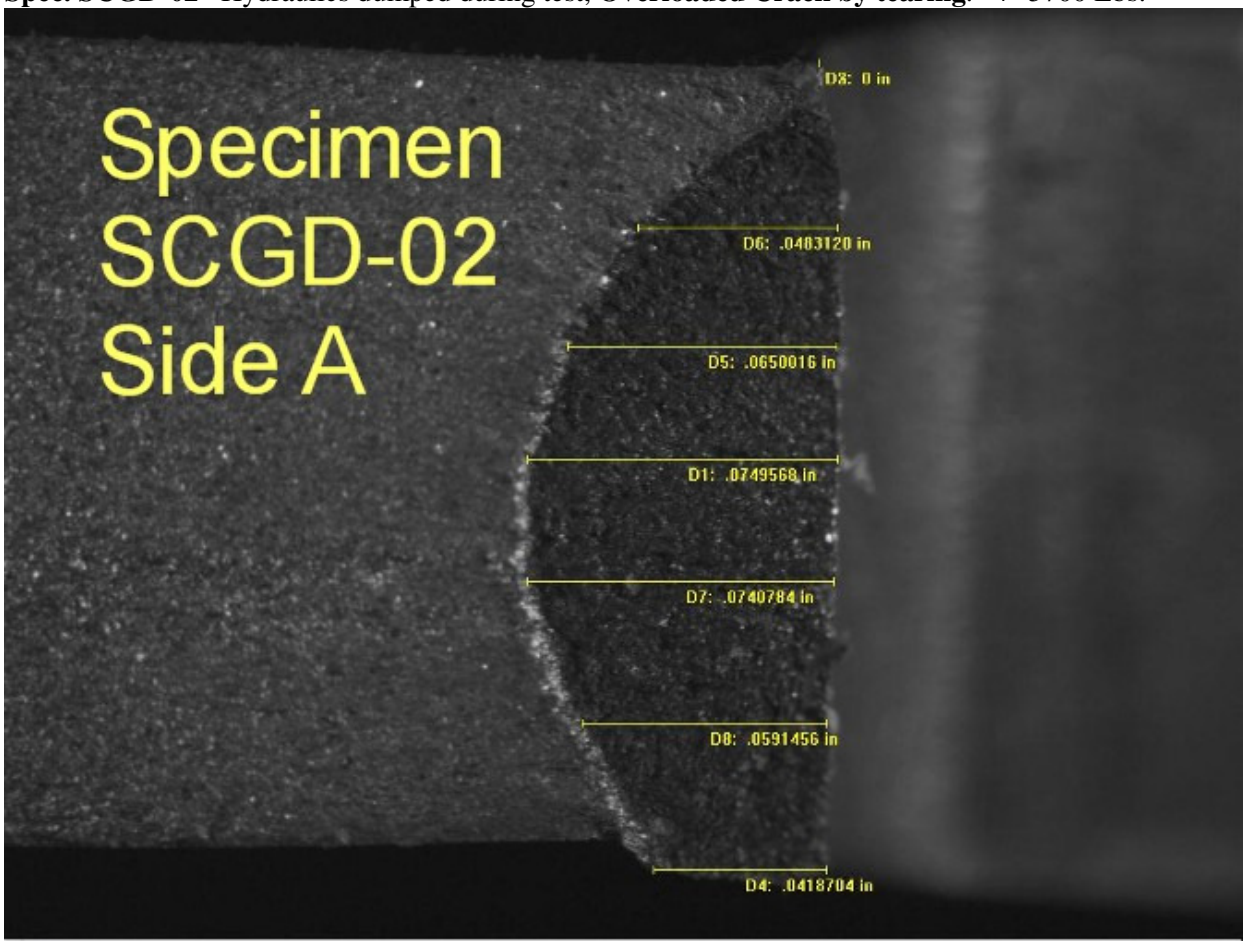
	Max. Load	Side		Cycles
SCGD-04	5200	A=.031	B=0 (F)*	9996

Crack in notch only.

Specimen Returned to Bettis. No Photos.

Condition D4

Condition D4 R = 0.2 notch radius = .060" 10 Hz
Spec. SCGD-02 Hydraulics dumped during test, **Overloaded Crack by tearing**. +- 5700 Lbs.



Side 1+ side/2=0.021" Crack Avg.=0.057"

Total Cycles with no crack 100200
Visual Data for specimen SCGD-02

Cycles	Side			
	A1	A2	B1	B2
3707	0.00	0.00	0.00	0.00
10K	0.00	0. 00	0.00	0.00
20K	0.00	0.00	0.00	0.00
50K	0.00	0.00	0.00	0.00
75K	0.00	0.00	0.00	0.00
88K	0.00	0.00	0.00	0.00
1,002K	0.00	0.00	0.00	0.00

Note: crack lengths inches

Specimen yielded by pump shutdown due to power surge. No Spreadsheet .

Specimen SCGD-03 Run out 1 Million Cycles at 10 Hz +-5700 lbs.
Spreadsheet SCGD-03

No Picture Specimen intact

Visual Readings

Cycles	Side			
	A1	A2	B1	B2
11.5K	0.00	0.00	0.00	0.00
50K	0.00	0.00	0.00	0.00
200K	0.00	0.00	0.00	0.00
400K	0.00	0.00	0.00	0.00
593K	0.00	0.00	0.00	0.00
770K	0.00	0.00	0.00	0.00
903K	0.00	0.00	0.00	0.00
1002K	0.00	0.00	0.00	0.00

Specimen stopped 1 million cycles +.

Note: crack lengths in inches

The Electric Potential Drop (EPD) system was devised, for these tests, as it was known the electrical environment in the testing area was noisy. This consisted of a 12 bit multi-function card and Version 7 of National Instruments Software and hardware. A 50,000 pound MTS frame, running MTS Systems TestStar 2S software, was used for test control and data acquisition.

All cracked specimens were heat tinted in an electric furnace at 900^{o}F. for 4 hours. A “half” hole was machined in the center of the specimen to accelerate post test fatigue to separation of specimens. Photographs were taken of the fracture surfaces and 7 point measurements taken for side and overall crack length averages.

Georgia Tech received 11 DEN specimens 8 with a notch radius of 0.002” and 3 each with a notch radius of 0.060”.

Specimen **SCGD-01** (radius = 0.060”) was used to calibrate the EPD system and yielded due to an electrical spike.

Designated calibration specimen **SCGD-09** has not been tested, and was to be used for further calibration of the EPD system.

All specimens are re-sealed in the poly bags and are boxed awaiting return to Bettis, as per terms of the contract.